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16. ABSTRACT
Reported are several procedures studied in an attempt to develop a less time consuming substitute for the sodium sulfate soundness test. Considered were procedures utilizing elastic fractionation, heavy media separation, autoclave degradation, freezing and thawing of aggregates, and others.

One procedure, detrition value test, correlates fairly well with soundness test losses for aggregates from one area of the state where the soundness test is a controlling factor in aggregate processing.

This procedure consists of the dynamic abrasion of water and aggregate in a 5 gallon bucket on a paint shaker. A test method was developed and an alternate specification to the soundness test requirement written for control of aggregate quality. The specification is currently limited to aggregates from the Santa Clara River area near Ventura.

17. KEY WORDS
Elastic fractionation, heavy media separation, freezing and thawing of aggregates, durability index, autoclave degredation, detrition value sodium sulfate soundness test

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DEPARTMENT OF TRANSPORTATION
DIVISION OF CONSTRUCTION AND RESEARCH
TRANSPORTATION LABORATORY

December 1975

TL No. 633476

Mr. C. E. Forbes
Chief Engineer

Dear Sir:

I have approved and now submit for your information this final research project report titled:

CONCRETE AGGREGATE DURABILITY TESTS

Study made by . . . . Concrete Branch

Under the Supervision of . . . . D. L. Spellman

Principal Investigator . . . . J. H. Woodstrom

Co-Investigator . . . . S. N. Bailey

Very truly yours,

George A. Hill

GEORGE A. HILL
Chief, Office of Transportation Laboratory

Attachment

ACKNOWLEDGEMENTS

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INTRODUCTION

For many years California and many other states have been interested in developing a procedure that would be an improved tool for measuring the ability of aggregates to resist degradation through impact, abrasion, or weathering. A good portion of effort has been directed toward a short term test that would replace the currently used Sodium Sulfate Soundness Test. Developing such a test procedure becomes complex. When you consider the wide range of materials used it is extremely difficult, if not impossible, to find a single test procedure that will apply to all materials. This is why we have a "battery" of tests to qualify aggregates for use in concrete. The Sodium Sulfate Soundness Test does measure some unique property. Some aggregates meet all other qualification requirements but this one.

Numerous test procedures have been developed in an attempt to evaluate the various properties of aggregates that relate to durability. Many of these tests have not proven effective and therefore are no longer in use. Other investigators, after many years of frustration, have concluded that no single test is likely to ever be a satisfactory measure of durability.

The Sodium Sulfate Soundness Test apparently had its beginning in about 1847 with the development of a "scientific" method of demonstrating the superiority of a stone to be used in construction of the Smithsonian(1). A Dr. Charles Page began a series of tests to "substitute the crystallization of the sulphate of soda for the freezing of water - - -." The present test was evidently a result of evolution, as well as the need to select sound aggregate for use in concrete.

With historical experience and dependence on the Sodium Sulfate Soundness Test, our search for a new test to measure aggregate durability was somewhat influenced by a desire to find a correlative test. Therefore, the Sodium Sulfate Soundess Test was used as a comparative measure of quality in most test development studies made.

In California, the Sodium Sulfate Soundness Test (Test Method No. Calif. 214)(2) is generally used in prequalifying a particular source of material, or periodically, to reevaluate a previously approved source. Due to the time involved in obtaining a result, the test cannot be used for control of daily production. It is used indirectly for this purpose, however, in conjunction with three plants that use benefication processes (heavy media and jigging) and stockpile processed aggregate. Without a daily check on quality these producers risk having 7-10 days production being rejected while awaiting results of soundness tests. Obviously a quicker test would be of great benefit in these cases. The aggregate deposits with good records of low soundness test losses present no serious risk to either the producer or the consumer.

Following is a brief history of the procedures investigated while searching for an improved and acceptable measure of the "durability" characteristic of aggregates. Among other things, early testing was performed using laboratory benefication systems patterned after two commercial processes used to upgrade aggregates. One system utilized specific gravity differentials; the other, the elastic modulus of the aggregate (elastic fractionation). Since these systems were used commercially to improve the quality of aggregate, it appeared that the same processes could be used to measure the quality of the end product.

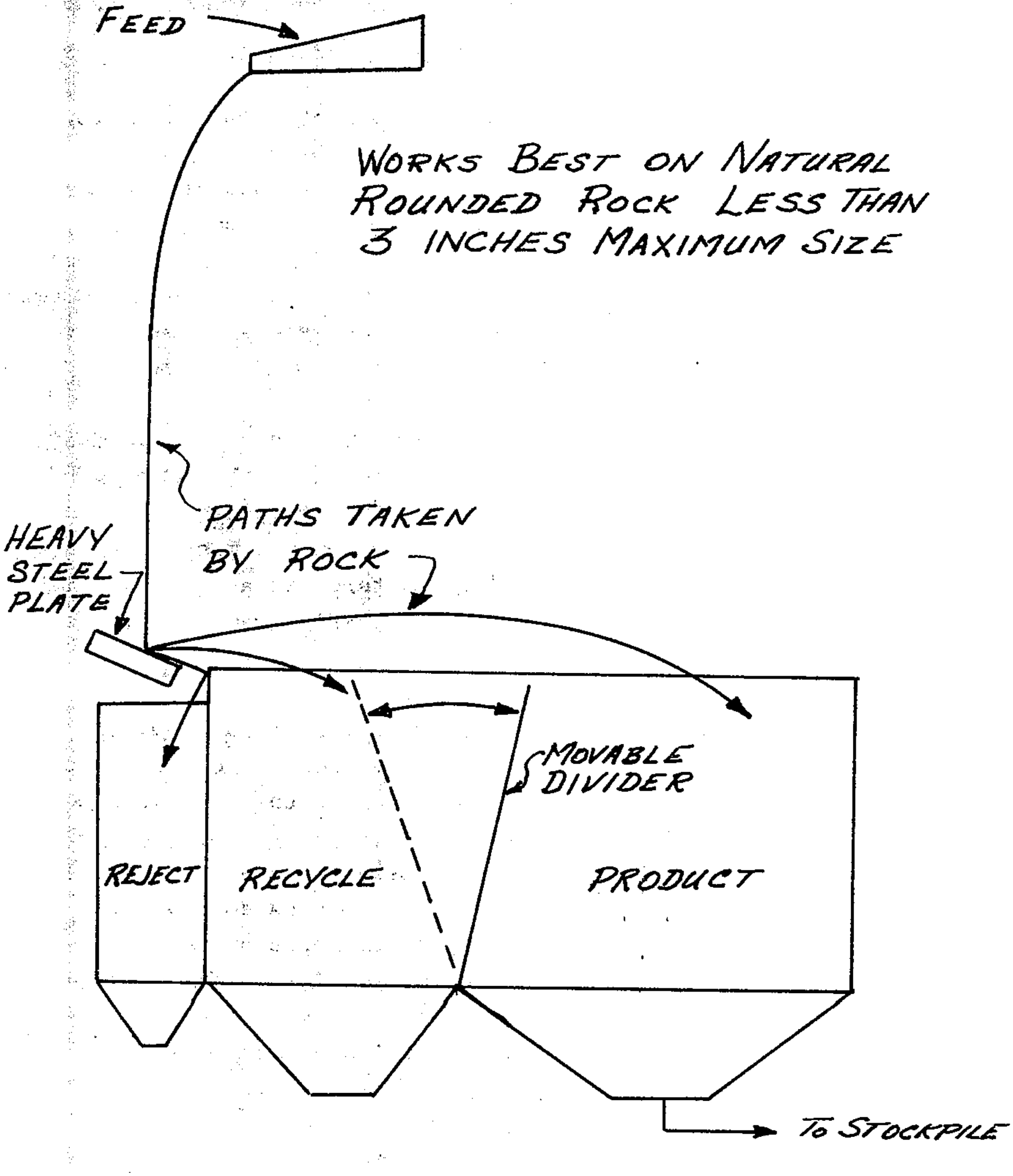
ELASTIC FRACTIONATION, 1958 - 1959

The first approach in our attempt to evaluate the durability of aggregate utilized the elastic modulus of the aggregate. In theory, hard elastic material will tend to bounce farther than soft in-elastic material when dropped in a controlled pattern on a hardened steel plate. Thus, the farther it bounces, the better it is. Softer material, on the other hand, will tend to deform or break when it hits the plate, and as a result, have a relatively short bounce distance.

A laboratory model of an Elastic Fractionation plant was designed and constructed with technical assistance from the developer of commercial equipment (Figure 1). Samples of aggregate were obtained that represented a cross-section of the many types and varying qualities that would be encountered in actual practice. These aggregates covered a range of specific gravity, particle shape, and geological classifications.

A river run gravel from a local source, and known to be of average quality, was obtained as a reference aggregate. The amount of soft, or low modulus particles in this source was to serve as a guide for comparison to other test aggregates. The Los Angeles Abrasion Test was chosen for the comparative measure of quality of the tests on the various sources of aggregate. Samples were subjected to LA Abrasion testing both before and after being subjected to elastic fractionation.

Samples to be tested were placed in a feeder-hopper so they could be dropped from a height of approximately eight feet onto the impact area of a tilted steel plate (see Figure 1). In the



ELASTIC FRACTIONATION

FIGURE 1.

original model, a series of collector bins were placed at various distances from the impact plate to collect the rebounding particles. Later, only 3 bins were used, reject, recycle and product. Material caught in the recycle bin during the first pass was recycled once more. Initial testing was performed using primary sized aggregate (1-1/2 x 3/4, etc.), but it was soon learned that a more effective separation was obtained when each individual size was processed separately (that is 1-1/2 x 1; 1 x 3/4; etc.). The main reason was that the impact area was much higher on the tilted steel plate for the larger particles than for the smaller ones. Thus the various sized particles had a tendency to interfere with each other. In testing each individual size separately, the feeder in the hopper could be adjusted so that nearly all particles struck the hardened steel impact plate at the designated "impact line".

In testing aggregates consisting mostly of hard brittle materials, such as a quartz, considerable breakage of the aggregate occurred. Sufficient energy was used in the fracturing of the particles to cause them to "fall short" near the "reject" end of the device. As a result, some material known to be very hard and durable in use ended up where only the soft unsound particles should have been.

The particle shape of the aggregates seemed to adversely affect the test results. Both crushed particles and natural flat and elongated particles of known sound material tended to accummulate in the "reject bins" near the rebound plate. Some rounded particles of known soft, poor quality materials were found to rebound and accumulate farther from the bounce plate than some of the more sound, crushed or misshaped particles.

Removal of poor quality material classified as "soft" did not proportionately improve quality as measured by the LA Rattler

Test (LART). A typical sample selected for testing had initial losses in the LA Rattler Test of 17.6% after 100 revolutions and 58% after 500 revolutions. Removal of 20% of the "soft" particles by Elastic Fractionation reduced the losses in the LA Rattler Test to 16.2% and 54% respectively. Rejecting an additional 15% of so-called "soft particles from the sample also did not result in proportionate reduction of LART losses.

Evaluation of all test data obtained from our Elastic Fractionation Testing indicated that although it may be a satisfactory system when processing ore which is predominately rounded in shape, there were too many problems when attempting to make a relatively "clean cut" between good and poor concrete aggregate.

HEAVY MEDIA SEPARATION 1960 - 1961

The second attempt to measure aggregate durability involved the principle of separation of lightweight material from heavier material by floatation in a heavy (high specific gravity) liquid or solution. Heavy Media Separation of sound and unsound particles of aggregate can be effectively done on a commercial scale when the specific gravity of the sound material is sufficiently different from that of the unsound material.

The quality of the end product depends on the amount of difference in the specific gravities and can be varied as needed by adjustments to a higher or lower specific gravity of the solution. However, within reasonable limits of separation, commercial heavy media plants cannot guarantee that the aggregate product produced will pass the Sodium Sulfate Soundness Test. Sometimes even high specific gravity particles can be "unsound" when evaluated by the Sodium Sulfate Soundness Test.

In order to help relieve the testing time problem a program was undertaken to find or develop a test procedure that would rapidly determine the suitability of the end product. Production was partly tied up in stockpiles of processed material awaiting the results of soundness tests. The delay in obtaining the soundness results causes considerable inconvenience and delay, and some cost to those producers, especially when test samples fail to meet specified requirements.

A laboratory model of a heavy media system was constructed in an attempt to utilize the relationship between the specific gravity and quality of some aggregates. The commercial heavy media plants utilize ferrosilicon and magnetites and water to achieve the high specific gravity solutions. In these plants, the circulation and recovery of the ferrosilicon and magnetite required an elaborate system of expensive equipment considered excessive for a laboratory model. For laboratory tests, acetylene tetrabromide diluted with carbon tetrachloride was used to create the heavy media solution. This combination could easily be adjusted to produce specific gravities from about 2.0 to 2.8.

One of the primary concerns in setting up the lab model was operator safety. The solutions selected are highly toxic, both from breathing and from contact with the skin. Although toxicity is most likely to occur from breathing the fumes, an operator would undoubtedly find it far too unpleasant to inhale enough of the fumes to be permanently harmful. The lab model was built in a well ventilated room with a down-draft ventilator fan to remove the toxic fumes which are heavier than air. Provisions were made to process the materials with as little chance of contact with the skin as possible.

The Sodium Sulfate Soundness Test was selected as the comparative measure of quality of the various test samples processed. It was this test that usually controlled the acceptance or rejection of the aggregate from all producers who used the heavy media plants to beneficiate their products. It was also this test that we hoped to eliminate and our goal was to develop a procedure, using our heavy media test, that would predict the Sodium Sulfate Soundness loss in not more than 1 day.

To determine the effectiveness of our lab setup, we obtained, from a commercial heavy media plant, samples of their "pit-run", "float" and "sink" materials as well as the specific gravities of the solutions that produced them. When these samples were processed through our plant at the same gravities, the results compared very favorably with those from the commercial plant as to the percentages of float and sink materials.

The aggregates selected for the preliminary development of this procedure were from sources containing fairly high percentages of shale and sandstone and with a record of high sodium sulfate soundness test losses. These sources were selected as we knew some of the "problem" aggregate particles had specific gravities much lower than the "sound" particles in the pit.

To test the effects of the aggregate separation by gravity on improving the quality of the samples, sodium sulfate soundness tests were performed on both pit run and beneficiated samples. (Duplicate samples were prepared for soundness and heavy media tests.) A geologist adjusted the split samples so the percentage of shale and sandstone was the same in each duplicate sample. The adjustment was made on each individual size in the samples, that is the 1-1/2" x 1", 1" x 3/4", etc.

From the various comparisons that were made, it was evident that the results were affected not only by the percentage, but also by the type of shale or sandstone. Equal percentages of "float" or "reject" material did not always result in equal soundness losses.

Further study showed that in one source, material that could be classified as siltstone, shale or sandstone actually covered a wide range of specific gravities and material composition, each with a different reaction to the soundness test. The variation encountered was an indication that a clear cut correlation between Heavy Media Separation and Sulfate Soundness loss could probably not be achieved, at least not with the character of the material being tested.

The heavy media process is presently used intermittently by two aggregate producers in California. That the process upgrades the quality of their product is beyond question. Plant production can be adjusted to produce aggregate that will meet our soundness loss requirements, though there are still some minor problems. At times, when it appears that a product should meet soundness requirements, it fails to do so, even when the specific gravity of the solution is held nearly constant. This is probably the result of a situation similar to what we experienced with the shale and sandstone; material very similar in some respects reacting very differently to the test.

Our goal to control plant production with laboratory type heavy media test was not achieved. The failure was partly due to anomalies that developed in the character of the particles themselves. Another reason for abandoning further development was the potential health hazard associated with the liquids used. While a small ferrosilicon type plant could have been constructed, costs and other factors caused us to look for other possible solutions to the problem.

The internal pressure exerted on aggregates by the formation of salt crystals in the soundness test has long been compared to the pressures created when water in the aggregates turned to ice during freezing. Subjecting the aggregate particles to rapid freezing and thawing cycles appeared to offer a safe and rapid procedure that could be used as an alternative to the more complex and time consuming Sulfate Soundness Test.

Duplicate samples were tested by both rapid freezing and thawing cycles and by the regular Sodium Sulfate Test. The evaluation of the freezing and thawing results was made by using the same procedures specified in the Sulfate Soundness Test, Test Method No. Calif. 214. After the specified number of freezing and thawing or soundness cycles were completed, each size of aggregate was sieved over a sieve with openings one-half the size of the sieve on which the aggregate was originally retained when being prepared for the test. In addition to testing "pit run" and "product" samples of aggregate from a plant using heavy media separation, test samples were "fabricated" with various percentages of shale and sandstone to give a wide range of test values.

Test results indicated there was little correlation between the losses resulting from equal numbers of cycles of sodium sulfate exposure and freezing and thawing. Increases in the percentage of shale in a sample generally resulted in increased soundness loss, but losses resulting from the freezing and thawing test did not increase a proportionate amount.

Again, the type of shales and sandstones in a sample seemed to affect the results (6) as much as the mere percentages of these materials. The type of breakdown of the different materials when subjected to the cycles of the two test procedures also had a direct relation to the indicated losses.

For example, the shales when exposed to cycles of Sodium Sulfate Testing seemed to disintegrate into a type of "mud". This permitted the material to easily pass the half size sieve used to determine test loss, thus indicating a high loss in the test.

In the freeze-thaw test however, similar shale particles separated on cleavage planes into flat pieces that would be retained on the half size sieve; thus indicating a lower loss in the test. By increasing the number of freezing and thawing cycles, these flat pieces could also be reduced to the same type of "mud" as resulted from the Sodium Soundness Test. This mud would now pass the half size sieve indicating a higher loss. The additional test cycles, however, would partly defeat the purpose of the project which was to develop a test preferably requiring no more than 1 day to complete.

This additional breakdown process did however result in a better correlation of the two tests.

DURABILITY INDEX, 1965

A test method (Test Method No. Calif. 229, Method of Test for Durability Index) (2), had been developed that measured the "durability" of base material aggregates in a matter of minutes. Its application to highway construction was presented to the Highway Research Board, January 1964 (3). Evaluation of this procedure as applied to concrete aggregate became the next step in our search for a concrete aggregate durability test.

Previous research had established a relationship between the Durability Index of Fine Aggregate (Df) (Test Method No. Calif. 229) and the Sodium Sulfate Soundness loss of the fine material (4). An alternative specification for fine concrete aggregate resulted from this relationship. It is:

"The Sodium Sulfate Soundness requirement for fine aggregate will be waived provided the durability index (Df) of the fine aggregate is 60 or greater when determined by Test Method No. Calif. 229."

The correlation between soundness and the durability factor of fine aggregates gave hope that a similar correlation existed for the coarse aggregate.

In addition to special samples obtained for this project, routine coarse aggregate samples that had been submitted for Sodium Sulfate Soundness testing were also tested for the Durability Index Test. No correlation between test results was found. It appeared that the two procedures were measuring different aggregate properties. The scope of the two test procedures would indicate they are intended to measure different types of degredation.

The Durability Index Test by definition is a procedure for determining the relative resistance of an aggregate to producing detrimental clay-like fines when subjected to the prescribed method of degradation; namely, agitation of the aggregate in the presence of water. The degraded product produced is a very fine grained material generated as the aggregates rub against each other.

The Sodium Sulfate Soundness Test is a procedure to determine the resistance of an aggregate to disintegration by alternate exposure to a saturated solution of sodium sulfate and oven drying. The degradation of the aggregate can result in at least three distinct products, all of which are found in aggregates tested from the river valley where heavy media plants are in operation. Siltstone or sandstone degraded into loose sandy particles; shales end up either a loose mud-like material or flakes, depending on the type and condition of the shale; poorly cemented granitic and fissured rock will break into smaller but still sound particles. The degradation products are relatively grainy as compared to the fine, clay-like material generated by the Durability Index Test. While the general approach appeared promising, it was obvious that the Durability Test procedure would have to be changed if end products (degradation) were to be similar.

Some thought was then given to developing a test that might apply to a limited geographical area of the state even if no test could be developed for statewide application.

Further efforts were then concentrated on development of a test that would measure quality only of aggregate produced by beneficiation, either heavy media or jigging. An additional literature search disclosed some work by others in recent years along the line of "durability testing".

1. "Rattler Degradation". (Degraded material from the L.A. Rattler Test is used to determine liquid limit, plastic index, sand equivalent, and gradation.)

2. Compactor Degradation. (Material is degraded in a mechanical compactor, then tested for sand equivalent and gradation.)

3. Olympia Degradation.(5) (Material in jars is degraded while rolling on a Deval Abrasion machine, then abraded material is used for sand equivalent and percent passing No. 10 and 200 sieves.)

4. Idaho Degradation. (Similar to Olympia Degradation.)

5. 5. Freeze-Thaw Degradation. (After subjecting samples to freezing and thawing cycles, material is tested for percent passing No. 4, change in grading, sand equivalent, liquid limit, plastic index of passing No. 4.)

6. Dept. of the Army - Engineering Tech. Letter 1110-2-40, May 1968, An Accelerated Expansion Testing (Using ethelene glycol) (7).

Unfortunately not all of these tests were correlated with the Sodium Sulfate Soundness Test nor did they appear to have any similarity.

AUTOCLAVE DEGRADATION - 1971

Consideration once again focused on the mechanics of degradation occurring during the Sodium Sulfate Soundness Test; the internal pressure exerted by the salt solution in the pores and crevices of the particles. A new procedure that produced a similar action was sought for the next area of study.

In a freezing and thawing type of test, part of the potential pressure that would be exerted by water expanding as it turns to ice is dissipated by the water migrating into small void spaces in the aggregate. In the Soundness Test, the pressure is exerted by another mechanism so relief from internal pressures by migration is not so likely. Better correlation of the two procedures might result if the expansion pressure from absorbed water could be made to occur instantaneously.

An autoclave used in testing portland cement was modified for a proposed test program utilizing steam pressure. This apparatus consists of a chamber capable of maintaining a steam pressure of 300 psi at a temperature of 300°F. A special quick release valve was installed that would permit nearly instant release of the pressure within the autoclave. In theory, any water within cracks or pores of a saturated aggregate sample within the autoclave would instantly expand into steam as the pressure was released. The expansion would exert internal pressure on the aggregate forcing the weaker particles to fracture. The loss was to be determined on sieves with openings one-half the size of the sieves on which the aggregate was originally retained when being prepared for the test, the same procedure as specified for Soundness Loss in Test Method No. Calif. 214. The degradation loss was also determined by sieving over the same size sieve used to prepare the sample, and over sieves with the next smaller openings. Some typical values are shown in Appendix A.

The first indications were that good correlations between the Autoclave Test and Soundness Test results were possible with only slight modifications. After sieving to determine the test loss, it was noted that many aggregate particles though partly fractured, remained intact. A modification to obtain the total separation of the fractured particles appeared necessary to improve the correlation.

The material, after being subjected to the autoclaving was placed in a rotating drum containing rubber rollers to complete the breakdown or separation of the fractured particles. The combination of procedures improved the correlation with the soundness test.

For some time it was the practice to determine losses by sieving the material after the autoclave portion of the test and again after the rolling process. It was noted however, that the best correlation occurred on samples that had a major portion of the measurable degradation take place during the rolling process. This led to speculation that perhaps all that was necessary was a modified LART or other impact type of test. Later studies showed the initial fracturing that resulted from autoclaving was necessary in order to achieve even fair correlation of results. A brief description of the autoclave test procedure together with some typical results of this testing program is found in Appendix A. Comparatively speaking, the time and effort required to prepare and test a sample was the same as the Sulfate Soundness Test, except in the soaking and oven drying. This was considered excessive and a better way was still needed.

When the results of a broad coverage of materials were examined, it was again shown that satisfactory correlation could be found only with certain types of material. Further pursuit of this idea appeared unproductive, though the results did suggest some sort of dynamic abrasion test might work. In addition the potential hazard present with the high pressure steam release made this approach less attractive.

MORE RECENT CONSIDERATIONS

All of the previous research indicated a test procedure that would improve upon the Soundness Test is not easily attained. The primary shortcomings of the Soundness Test are the time consumed in testing, high cost of the test and poor reproducibility.

Over the years various technical groups and individuals have struggled with finding ways of improving the Sulfate Soundness Test without much success.

One of the chief causes of variation in test results of the Soundness Test has long been considered to be the small size of the test sample. In the larger aggregate sizes in particular, the failure of only one or two particles can affect the test results to a considerable degree.

A larger test sample than that used for most of the previously considered tests was a primary condition for the next attempt to develop an alternative. The abrasive action of the Durability Index Test, together with some dynamic impact appeared promising. The next series of tests was designed to utilize the basic concept of the Durability Index Test, a larger, more representative sample of aggregate, and some vigorous dynamic action.

DETRITION VALUE TEST (DV) - 1972

The work in this part of the study was divided into three phases. The first phase was the development of a new test, "Detrition Value Test", and equipment. The second phase was to compare the results obtained with the new test and results of the Sodium Sulfate Soundness Test, using a selected number of aggregate samples from areas of high soundness loss. The third phase consisted of collecting and testing samples of aggregate throughout the state and again comparing the test results with those of the Sodium Sulfate Soundness Test. Preliminary considerations of test sample size led to the selection of a 5 gallon paint bucket and a commercial paint shaker. This equipment is both relatively cheap and available.

A Red Devil Model 33 Paint Shaker, a timer, and 5-gallon paint buckets were prepared for the test program. In the first and second phases of the test, the paint shaker was securely mounted to a 500-lb steel plate. In Phase 3, it was bolted to a concrete floor with a rubber bushing and anchors that were made for its use as a paint shaker. (These different configurations are not believed to have any significant effect on results.) The machine was operated with the 5-gallon bucket held in the horizontal position. Figure 2 shows a picture of the paint shaker and the testing equipment.

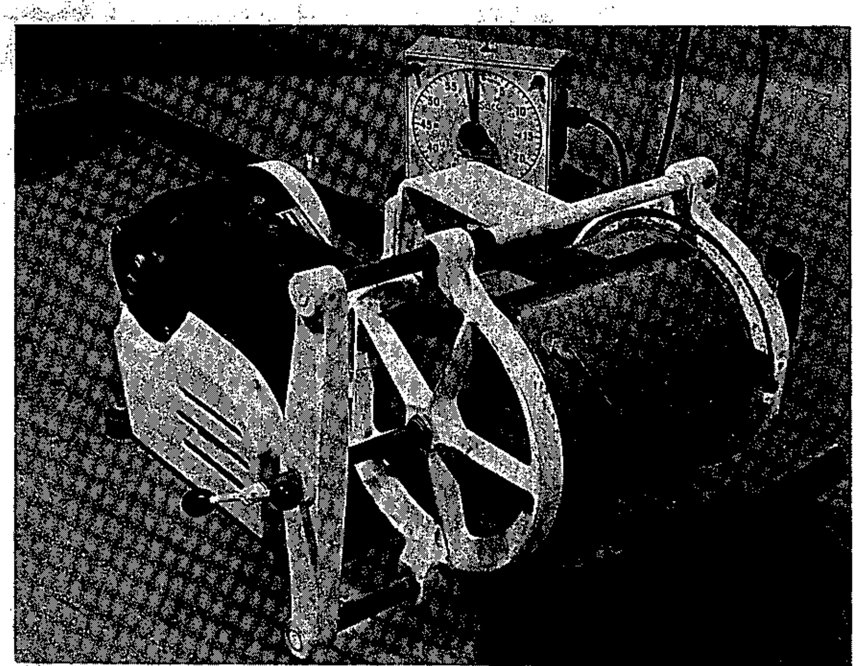


Figure 2

Basically, the test sample is weighed, placed in the 5-gallon bucket with water, and given a thorough agitation on the paint shaker. The sample is then sieved over the #4 sieve and the retained material is again weighed. The difference between the initial and final weight divided by the original weight x 100 is the loss.

Two aggregate sources were used in Phase 1 - Fair Oaks aggregate from the Sacramento Area, and S.P. Milling Company material from the Santa Clara River near Ventura. The S.P. Milling Company material is processed through a heavy media plant. The samples from the latter source were supplied in three qualities: (1) pit run, (2) beneficiated, and (3) rejected or float material.

In developing the test procedure, one of the first considerations was sample size. To determine the effects of the sample size, a series of tests was run using the following quantities retained on a No. 4 sieve: 2500 grams, 5000 grams, 7500 grams, and 10,000 grams. The losses for these tests are plotted on Figures 3 and 4. It can be seen that as the sample size increased, the losses generally decreased. A 7500-gram sample was selected for the test. For this size sample, the 2250 ml of water used is enough to just cover the aggregate in the 5-gallon container. The space left for sample movement appeared to be adequate. The loss for these samples was determined as the amount of material passing the No. 4 sieve.

After the sample size and the amount of water to be used were selected, it was then necessary to determine the length of time for the agitation of the sample and the effect of different times on the results. Figures 5 and 6 show the effect of agitation time on the DV losses. It can be seen from these figures that as the agitation time is increased, the DV losses also increase. The time of 30 minutes was selected as being a reasonable time for the test while maintaining a substantial difference in measured losses.

In Figures 3, 4, 5, and 6 it can be seen that the "reject" or "float" material in all cases had the greatest loss, the pit run material had the next lower loss, and the Fair Oaks aggregate had the smallest loss. The test method developed in Phase 1 is attached as Appendix B.

Phase 2 involved measuring the response of the adopted test method to changes in the quality of the aggregate. In order to evaluate the test responses, all samples were batched to the same grading as shown in the following table:

PERCENT LOSS V/S SAMPLE SIZE - 20 MIN. AGITATION

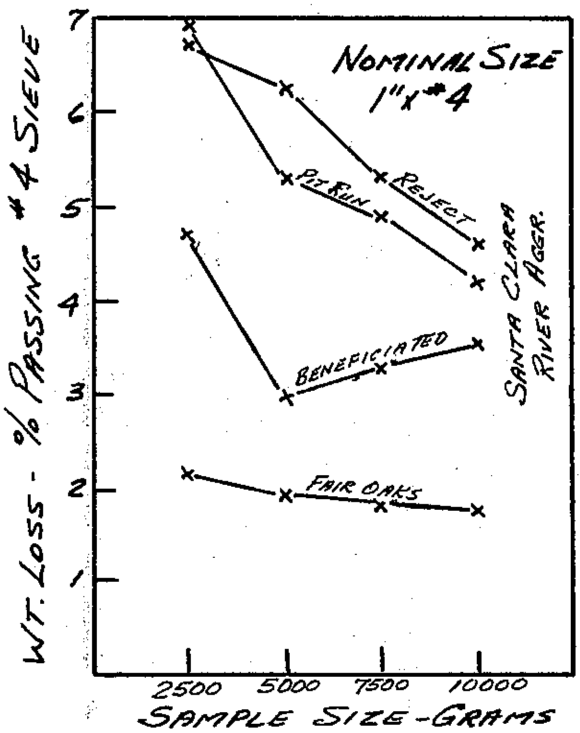


FIG. 3

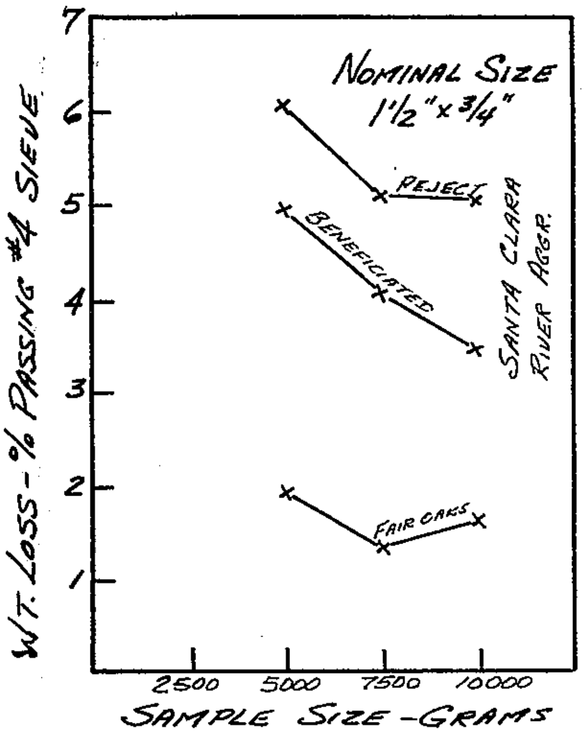


FIG. 4

PERCENT LOSS VS AGITATION TIME - 7500 GR. SAMPLE

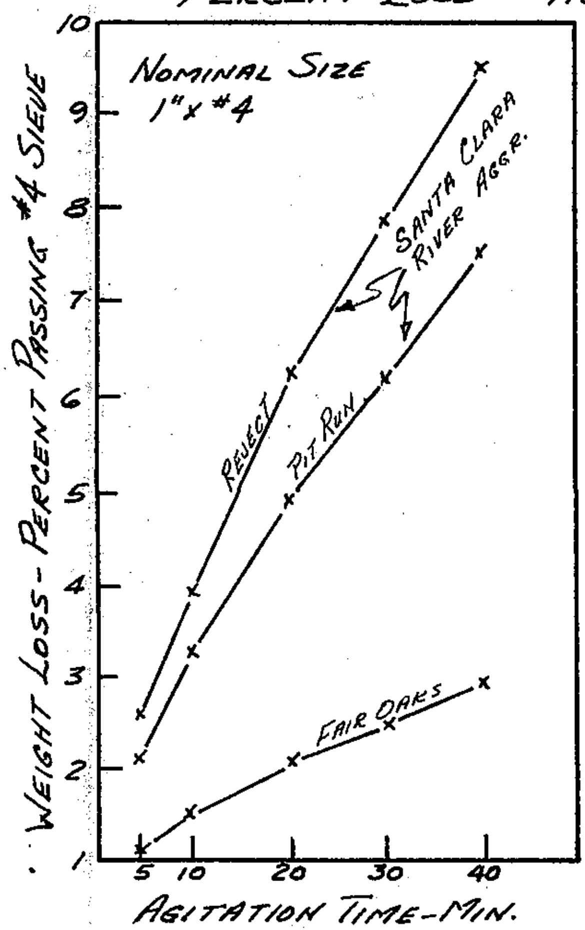


FIG. 5

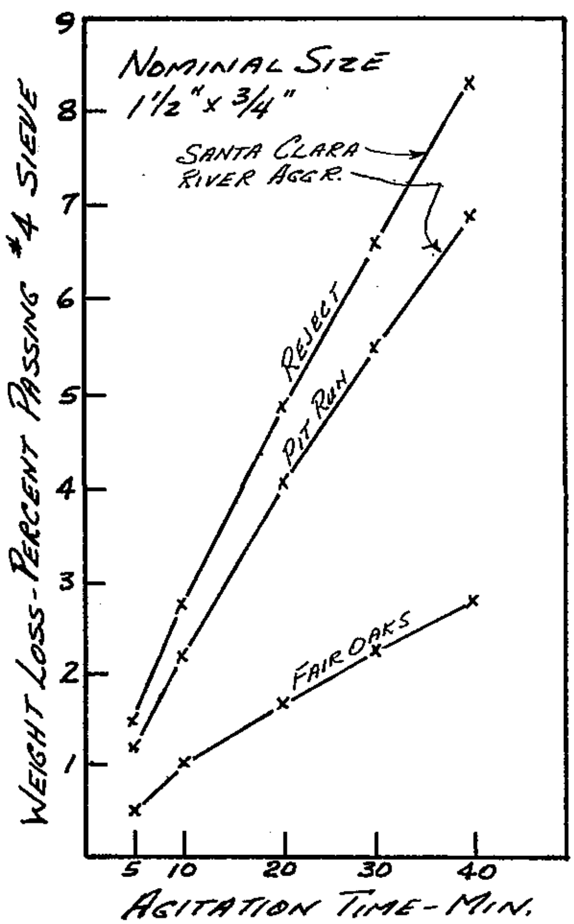


FIG. 6

Sieve Sizes	% of Sample
1" x 3/4"	30
3/4" x 1/2"	30
1/2" x 3/8"	30
3/8" x No. 4	10

Both the Detrition Value (DV) and Sodium Sulfate Soundness tests were run on two replicate samples prepared from each of the five blends shown in the following table:

	Composition, %		No of Tests	
Blend	Beneficiated	Reject	DV	Na_2SO_4
1	100	0	2	2
2	75	25	2	2
3	50	50	2	2
4	25	75	2	2
5	0	100	2	2

Graphs showing the percent weight loss versus percent beneficiated aggregate for DV and Soundness Tests are shown in Figure 7. A line was drawn connecting the averages of the two replicates.

Essential statistical data are as follows:

	Standard Error of Estimate (sy)	Range (R)	$\frac{sy}{R}$
DV	.182188	2.58	.0706
Soundness	1.59883	19.0	.0841

DETRITION VALUE & SOUNDNESS TESTS
WEIGHT LOSS V'S % BENEFICIATED MATERIAL

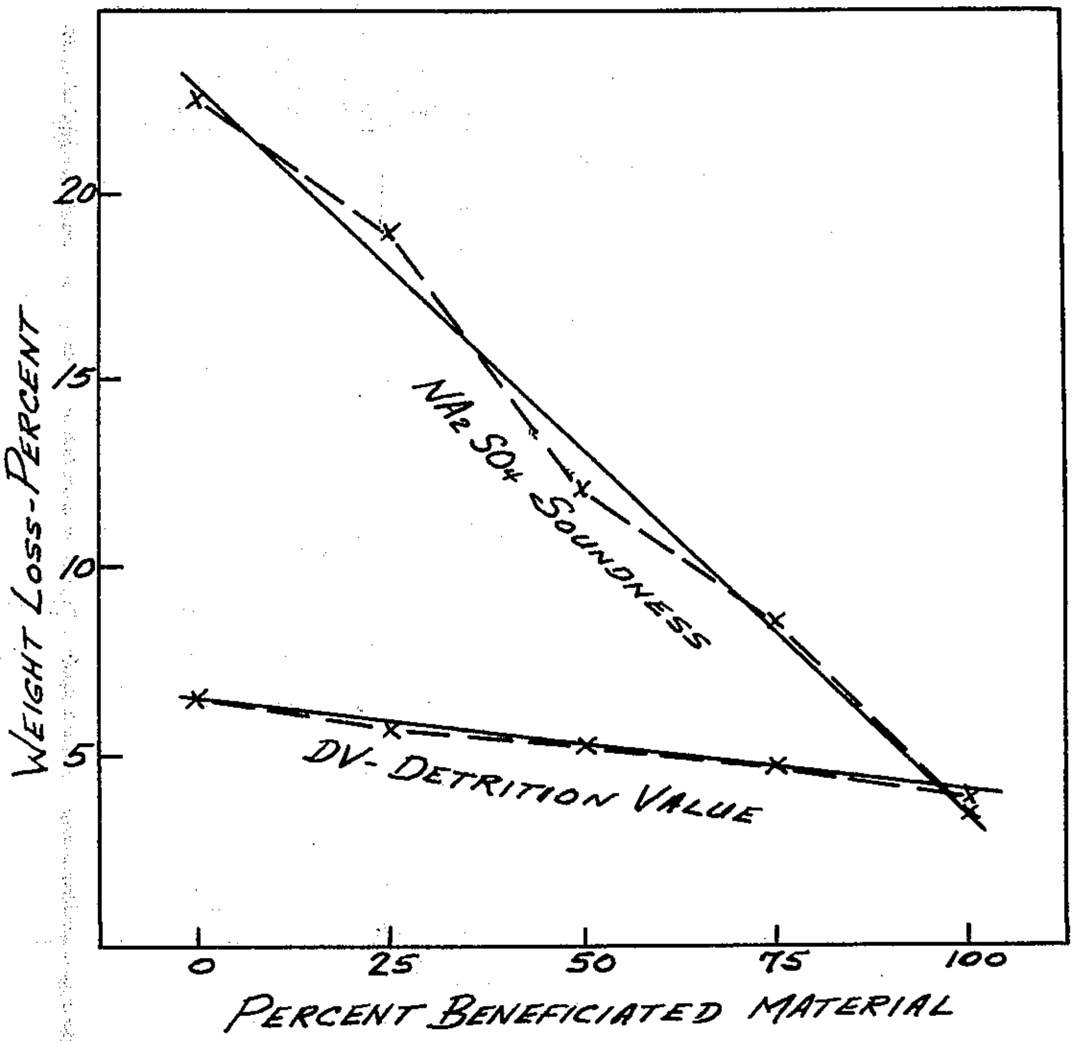


FIG. 7

The conclusion drawn from the above calculation of the standard error divided by the range was that DV for the materials tested is at least as good as the soundness test from the standpoint of relative response versus consistency. While the result of this series of tests indicated a workable relationship between the two tests, it will be shown later that when other types of material are used, the relationship is not as good.

Phase 3 involved comparative DV and Soundness Testing on duplicate samples from 16 aggregate sources located throughout the state, to learn more about the applicability of the DV test for statewide use.

Coarse aggregate in the two primary nominal sizes (1-1/2" x 3/4", and 1" x No. 4), was sampled from 16 sources for a total of 32 test samples. Four test portions from each sample size were prepared; two replicates were split in the "as received" condition for DV testing, and two replicates were batched for soundness testing after the specimen had been processed and graded.

The following table shows how aggregate from 16 sources was used to produce 64 test samples each for DV and Soundness Tests:

Number of sources	16			
Nominal Size (2)	1-1/2" x 3/4"		1" x No. 4	
Number of Test Samples	16		16	
Test Run	DV & NA_2SO_4		DV & NA_2SO_4	
Replicates	2	2	2	2
Total Tests	32	32	32	32

Appendix C lists the sources of the aggregates and the test results. Figure 8 shows the soundness test losses versus the DV test losses for these 16 sources.

DETRITION VALUE VS SOUNDNESS LOSS
16 CALIFORNIA SOURCES

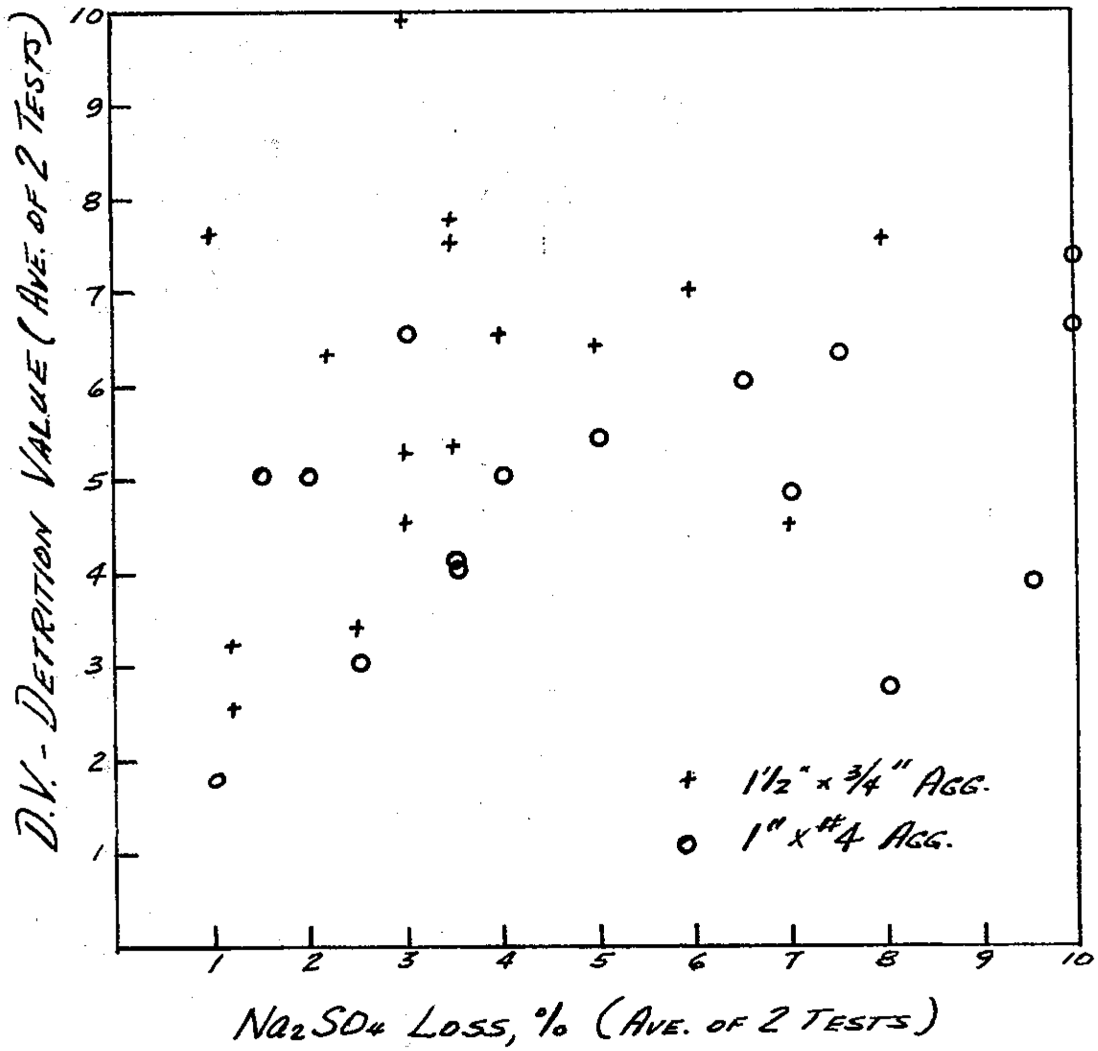


FIGURE 8

While there appears to be some correlation between DV and soundness loss, there are many cases of relatively low soundness losses and high DV's. This may be a result of rock character; i.e., brittle and subject to breakage by detrition but resistant to breakdown by the Sodium Sulfate Solution action. No statewide application is possible until reasons for these anomalies are better understood. The relationship should be more closely studied at the specification limit of 10% as values below this limit are of less concern. Testing errors are relatively large percentagewise, at low loss values.

CONCLUSIONS AND IMPLEMENTATION

Of the various approaches that were pursued to provide an adequate substitute for the sodium soundness test, the Detrition Value Test appears to offer the most promise with certain aggregate types. A special provision to the specifications implementing the use of the Detrition Value Test where appropriate is proposed as follows:

"SOUNDNESS REQUIREMENT FOR COARSE AGGREGATE.--The soundness requirement in the fifth paragraph of Section 90-2.02, "Aggregate", of the Standard Specifications will be waived for coarse aggregate, provided that the Detrition Value, DV, of the coarse aggregate as determined by Test Method No. Calif. 544, is ____ or less for individual test results and ____ or less for the moving average.

Evaluation of test results shall conform to the provisions in Section 6-3.02, "Statistical Testing", of the Standard Specifications.

The application of this specification and the values used must be based on a knowledge of the particular aggregate source and a correlation of test results of the two tests involved. Obviously there are several test alterations that might be made to improve correlation. For example it has been suggested that all material prepared for the test should be retained on the 3/8 inch sieve and losses still determined by material passing the No. 4 sieve. It has also been considered that the primary sizes should be farther divided into more fractions before testing, i.e., instead of putting all the 1 x No. 4 material in the 5-gallon bucket, the 1" x 3/4", 3/4" x 1/2", 1/2" x 3/8", etc. should be tested separately. Any future development work may include these suggestions.

REFERENCES

1. Douglas, Paul H. and James, William K., Sandstone, Canals and the Smithsonian.

2. State of California, Department of Public Works, Division of Highways, Materials Manual, Vol. I.

3. Hveem, F. N., Smith, T. W., "Durability of Aggregates", (Presented at the 43rd Annual Meeting of the Highway Research Board, January, 1964).

4. Frazier, C. A., "Correlation of Sodium Sulfate Soundness Test With Durability Index of Concrete Sands", Final Report May 25, 1965.

5. Washington State Highway Commission, Department of Highways, Materials Division, Laboratory Manual, Vol. I, W.S.H.D. Test Method No. 113-A.

6. Memo - D. Spellman to C. Gates, June 24, 1969, Subject - Soundness Tests.

7. Department of Army Engineering Technical Letter 1110 - 2-40, May 1, 1968, "An Accelerated Expansion Test".

APPENDIX A

AUTOCLAVE DEGRADATION LOSS
GENERAL PROCEDURE

Scope

This test causes degradation of aggregate particles by internal steam pressures created by the quick release of pressure of an autoclave containing the aggregate samples.

Special Equipment

1. Autoclave conforming to the requirements found in ASTM Designation: C151 and equipped with a quick pressure release valve of one inch minimum diameter.

2. Reinforced wire meshed baskets with covers that may be securely latched. Shape and dimensions of baskets to be such that several can be conveniently placed in autoclave.

Tentative Procedure

1. Prepare test specimen from each sieve size of material as specified in Test Method No. Calif. 214.

2. Place each specimen in separate basket and soak for a minimum of 18 hours.

3. After soaking, immediately place in autoclave containing enough additional water to maintain an atmosphere of saturated steam vapor during the period of autoclaving process.

4. Bring autoclave to desired pressure as prescribed in ASTM Designation: C151 and maintain for 3 hours.

5. At end of 3-hour period, open pressure release valve, then remove autoclave head and test specimens.

6. Oven dry test specimens and determine weight loss as prescribed in Test Method No. Calif. 214.

Test Results

Some typical test results of the Autoclave Degradation Loss Test Method follows:

The "A" designation signifies that the size fraction was obtained from the 1-1/2" x 3/4" primary aggregate size, and the "B" designation signifies that it was obtained from the 1" x No. 4 size. "Full Size", "Next Finer Size", and "Half Size", refer to the loss on the lower size sieve of the fraction being tested, the next finer size, and the nominal half size of the fraction being tested, respectively.

AUTOCLAVE DEGREDATION VS Na_2SO_4 SOUNDNESS LOSS

SAMPLE TEST SIZE "A" FROM 1½x¾ "B" FROM 1x4		AUTOCLAVE DEGREDATION - % LOSS: AFTER AUTOCLAVING, LOSS ON SIEVE — FULL SIZE	NEXT SMALLER	HALF SIZE	AFTER ROLLER FRACTURING, LOSS ON SIEVE — FULL SIZE	NEXT SMALLER	HALF SIZE	% LOSS-Na_2SO_4 SOUNDNESS PER T.M. 214 LOSS ON ½ SIZE SIEVE
SIMI ROCK - SIMI VALLEY 68-1241								
1½x1	A	—	—	—	5.3	3.1	2.4	—
1x¾	A	—	—	—	8.1	6.0	4.5	—
1x¾	B	—	—	—	6.9	5.0	3.8	—
¾x½	A	—	—	—	3.6	2.2	2.0	—
¾x½	B	—	—	—	6.8	3.9	3.4	—
½x⅜	B	—	—	—	7.8	6.0	4.5	—
⅜x4	B	—	—	—	9.6	8.5	7.0	—
FINLEY-DUNCAP-FORT JONES 69-1610								
1½x1	A	—	—	—	4.0	1.9	1.2	5.0
1x¾	A	—	—	—	5.8	2.0	0.9	1.0
1x¾	B	—	—	—	5.2	2.1	1.2	1.0
¾x½	A	—	—	—	3.5	1.4	0.9	3.0
¾x½	B	—	—	—	5.3	2.4	1.5	1.0
½x⅜	B	—	—	—	7.4	5.3	3.0	2.0
⅜x4	B	—	—	—	6.0	3.6	2.2	2.0
BAXMAN-10 MILE CREEK 66-3019								
1½x1	A	18.1	13.9	9.6	26.0	19.8	12.6	—
1x¾	A	14.4	10.7	7.2	21.1	15.2	10.4	—
1x¾	B	13.2	10.5	7.6	19.0	14.4	10.4	—
¾x½	A	1.9	1.3	1.2	7.5	5.6	3.3	—
¾x½	B	11.5	8.3	6.6	17.0	12.8	10.4	—
½x⅜	B	8.6	6.2	3.7	25.3	19.4	12.2	—
⅜x4	B	3.8	2.9	2.0	17.3	14.0	9.6	—
FORD GRAVEL CO.-UKIAH 66-3077								
1½x1	A	4.9	3.0	2.2	9.7	5.6	3.3	6.6
1x¾	A	3.4	1.9	1.5	8.5	5.2	2.6	7.6
1x¾	B	4.9	2.6	1.8	10.5	5.6	3.7	—
¾x½	A	1.8	0.5	0.5	7.1	2.7	1.7	—
¾x½	B	4.8	2.4	1.9	9.6	5.3	4.0	7.5
½x⅜	B	4.2	1.8	1.5	10.7	6.6	3.5	8.0
⅜x4	B	1.0	0.8	0.6	5.5	4.2	3.3	5.0

AUTOCLAVE DEGREDATION Vs Na_2SO_4 SOUNDNESS LOSS

SAMPLE TEST SIZE "A" FROM 1½x¾ "B" FROM 1x4	AUTOCLAVE DEGREDATION - % LOSS: AFTER AUTOCLAVING, LOSS ON SIEVE — FULL SIZE	NEXT SMALLER	HALF SIZE	AFTER ROLLER FRACTURING, LOSS ON SIEVE — FULL SIZE	NEXT SMALLER	HALF SIZE	% LOSS-Na_2SO_4 SOUNDNESS PER T.M. 214 LOSS ON ½ SIZE SIEVE
NYLAND QUARRY AGG. - 67-3199							
1½x1 - A	6.4	3.4	1.7	16.0	10.2	4.9	8
1x¾ - A	6.4	3.0	1.7	16.2	10.1	5.8	8
1x¾ B	3.4	1.4	0.9	13.4	5.9	3.0	—
¾x½ - A	5.3	0.5	0.5	9.8	5.1	3.8	—
¾x½ - B	5.3	1.6	1.1	15.1	7.8	5.9	6
½x⅜ - B	4.3	1.9	1.4	17.3	13.3	10.0	10
⅜x4 B	1.2	0.9	0.6	12.0	9.8	6.5	7
GILLIBRAND-SIMI VALLEY 68-1686							
1½x1 - A	6.3	2.9	1.8	11.1	6.0	4.5	6
1x¾ - A	9.1	6.0	3.4	14.3	9.7	6.7	11
1x¾ - B	5.1	2.5	2.1	12.3	8.1	5.5	17
¾x½ - A	2.9	1.4	1.3	8.8	6.7	5.7	—
¾x½ B	6.4	4.5	3.1	14.1	10.3	8.5	19
½x⅜ B	8.5	6.6	5.2	18.5	14.5	11.0	—
⅜x4 B	4.1	3.4	3.0	13.2	9.4	6.7	24
FENTON MATERIALS-MONARCH 68-1820							
1½x1 A	11.7	9.8	7.0	13.2	11.4	8.7	4
1x¾ A	6.0	5.0	3.7	7.7	6.5	5.0	1
1x¾ B	6.1	3.9	2.8	8.1	5.9	4.5	2
¾x½ A	1.2	0.3	0.3	3.7	1.9	1.4	—
¾x½ B	3.5	1.8	1.5	5.9	3.3	2.8	—
½x⅜ B	2.0	1.2	0.6	5.0	3.0	2.0	2
⅜x4 B	3.1	0.8	0.7	5.9	3.3	2.2	1
CAL ROCK-BAKERSFIELD 66-3011							
1½x1 A	6.0	4.1	2.4	8.6	5.5	4.1	2
1x¾ A	6.2	3.7	2.5	8.7	5.5	4.0	4
1x¾ B	2.1	0.7	0.5	4.5	2.8	1.8	—
¾x½ A	1.6	0.6	0.5	5.0	2.1	1.8	—
¾x½ B	2.3	0.8	0.7	7.4	3.5	2.7	4
½x⅜ B	3.7	2.4	1.6	9.7	7.6	5.3	5
⅜x4 B	1.1	0.6	0.4	7.1	5.4	3.9	5

AUTOCLAVE DEGREDATION Vs Na_2SO_4 SOUNDNESS LOSS

SAMPLE TEST SIZE "A" FROM 1½x¾ "B" FROM 1X4		AUTOCLAVE DEGREDATION - % LOSS AFTER AUTOCLAVING LOSS ON SIEVE — FULL SIZE	NEXT SMALLER	HALF SIZE	AFTER ROLLER FRACTURING LOSS ON SIEVE — FULL SIZE	NEXT SMALLER	HALF SIZE	% LOSS-Na_2SO_4 SOUNDNESS PER T.M. 214 LOSS ON ½ SIZE SIEVE
P.C.A. - ELIOT 68-2712								
1½x1	A	12.4	9.8	6.3	17.9	14.9	9.2	1
1x¾	A	10.4	7.8	5.6	13.1	10.3	8.1	1
1x¾	B	3.7	2.3	1.4	7.0	4.8	3.2	—
¾x½	A	1.0	0.3	0.3	2.5	1.2	0.9	1
¾x½	B	4.1	0.8	0.6	5.0	2.6	2.0	—
½x⅜	B	4.8	2.6	1.7	6.7	4.3	2.8	—
⅜x4	B	1.0	1.0	0.8	3.5	2.9	2.2	—
F&J - HOSPITAL CREEK 66-2112								
1½x1	A	13.6	9.2	6.2	18.3	14.6	10.4	3
1x¾	A	8.1	5.2	2.5	12.5	9.4	6.9	5
1x¾	B	4.0	1.7	1.3	7.1	5.1	3.4	—
¾x½	A	0.5	0.2	0.2	3.0	1.4	0.8	—
¾x½	B	2.6	0.9	0.7	5.4	2.8	2.4	6
½x⅜	B	3.7	2.1	1.3	6.1	3.7	2.5	3
⅜x4	B	1.0	0.6	0.5	3.5	2.2	1.7	3
GILLIBRAND - SOLEDAD CANYON 70-1157								
1½x1	A	—	—	—	9.8	7.6	5.3	3
1x¾	A	—	—	—	9.3	5.5	3.8	5
1x¾	B	—	—	—	9.2	7.0	5.3	—
¾x½	A	—	—	—	4.9	2.4	1.6	—
¾x½	B	—	—	—	4.9	3.3	3.0	5
½x⅜	B	—	—	—	6.2	3.9	2.5	3
⅜x4	B	—	—	—	4.3	3.3	2.2	5
BECKHAM BROS. - BANNING 68-2032								
1½x1	A	—	—	—	11.9	8.8	5.6	—
1x¾	A	—	—	—	6.5	4.7	3.2	—
1x¾	B	—	—	—	6.4	3.8	2.3	—
¾x½	A	—	—	—	4.3	1.7	1.2	—
¾x½	B	—	—	—	3.6	2.3	1.6	—
½x⅜	B	—	—	—	7.8	5.7	3.9	—
⅜x4	B	—	—	—	6.4	4.2	3.0	—

TRANSPORTATION LABORATORY

State of California
Department of Transportation
Division of Construction &
Research

Test Method No. Calif. 544-A
December 5, 1974
(5 Pages)

METHOD OF TEST FOR DETERMINING THE DETRITION VALUE (DV) OF COARSE AGGREGATE

Scope:

The Detrition Value (DV) indicates resistance to breakdown of coarse aggregate when agitated in the presence of water.

Procedure:

A. Apparatus

1. Balance: A balance with a minimum capacity of 20,000 grams, sensitive to 1 gram, and accurate within 0.2% of the total test specimen weight.

2. Graduate: A graduated cylinder of at least 500 ml capacity.

3. Sieves: A box sieve and rocker assembly having U. S. Standard No. 4, 3/8-inch, and 3/4-inch sieves. See Figure I for specifications and dimension of recommended box sieve assembly.

4. Sample container: Paint bucket, 5-gallon capacity, with waterproof gasket equipped lid. Must be new, or clean and in good condition so that a waterproof seal can be obtained.

5. Automatic timer.

6. Agitator: Model 33A (5033), paint conditioner manufactured by the Red Devil Company. Other types of agitators are permissible provided the frequency, amplitude, and orientation of the bucket are the same as Model 33A (5033) and identical test results are obtained. Fasten securely to the floor or clamp to a base plate that weighs approximately 500 pounds.

7. Riffle splitter.

B. Materials

Water: Any potable water may be used.

C. Preparation of Test Samples

If the coarse aggregate for use in portland cement concrete is separated into two primary sizes, perform a DV test on each. Obtain approximately 20,000-gram samples from each primary coarse aggregate size stockpile.

D. Test Procedure

1. Using the box sieves and rocker assembly, sieve each primary size aggregate sample over the No. 4 sieve. To protect the No. 4 sieve, use the 3/4-inch and 3/8-inch sieves as covers. To prevent overloading of the sieves, process the sample in four or more portions. Recombine the retained No. 4 material from each portion.

2. After sieving as in 1, split and adjust each primary coarse aggregate sample to be tested to 15,000±400 grams. Split this adjusted sample to provide two approximately equal portions of the retained No. 4 materials.

3. Soak each of the 7500± gram test portions for a minimum of 30 minutes. (The soaking period of the two portions will have to be scheduled to comply with the time intervals specified in other sections of the test method.) At the end of the soaking period, agitate the sample while still immersed to remove any loosened fines.

4. After soaking as specified in 3, place one of the 7500±-gram test portions on the No. 4 sieve, tilt the sieve to approximately a 30° angle, and allow the material to drain for a period of 5 minutes ± 15 seconds.

5. Obtain and record the initial drained weight to the nearest gram.

6. Place the 7500± gram test portion in the sample container and add 2250 ± 20 ml of water. Place the cover on the container and clamp it in the agitator. Rotate the container so that it is horizontal at the midpoint of the cycle. Tighten the slip clutch and shake for 30 minutes ± 10 seconds.

7. Using the box sieves and rocker assembly, sieve the tested material over the No. 4 sieve as in Step 1. To prevent overloading the sieves, process the material in at least two portions. Immerse the sample in water and agitate to remove any loosened fines.

8. Recombine all retained No. 4 material on the No. 4 sieve, tilt the sieve to approximately a 30° angle, and allow the material to drain for a period of 5 minutes ± 15 seconds.

9. Obtain and record the final drained weight.

10. Test the second 7500± gram portion by the same procedure as above.

E. Calculations

1. Calculate DV:

$$DV = \frac{\text{Original drained weight} - \text{Final drained weight}}{\text{Original drained weight}} \times 100$$

2. Report the DV as the average values of the two 7500± gram portions of the sample.

3. If the DV loss on either primary coarse aggregate size exceeds the maximum allowable moving average loss by not more than two percentage points, it is permissible to calculate a "Batch DV Loss" for the coarse aggregate. This will allow a low loss on one primary size to compensate for a higher loss on another primary size in determination of specification requirements. If either primary size exceeds the maximum allowable moving average loss more than two percentage points, that primary size is considered to fail the specification requirement.

The Batch DV Loss shall be calculated on the weighted average basis shown below regardless of the actual proportions to be used.

2-1/2 in. Maximum

2-1/2 x 1-1/2-in.	----------------	34%
1-1/2 x 3/4-in.	----------------	33%
1-in. x No. 4	----------------	33%

1-1/2-in. Maximum

1-1/2-in. x 3/4-in.	---------------	67%
1-in. x No. 4	---------------	33%

Example:

Primary Aggregate	DV Loss	Weighted % to be Used	
1-1/2 x 3/4-in.	6	67	X 0.01 = 4
1-in. x No. 4	10	33	X 0.01 = 3.3
		Batch DV Loss	7.3

In the event that only one primary sized coarse aggregate is to be used (1-inch maximum concrete), the average DV loss determined in 1 above, shall not exceed the specified maximum.

F. Precautions:

Check the oil level in the agitator gear box at frequent intervals. Maintain the level above the black line on the oil gauge window with SAE 20 oil.

Attachment

End of Test Method No. Calif. 544-A

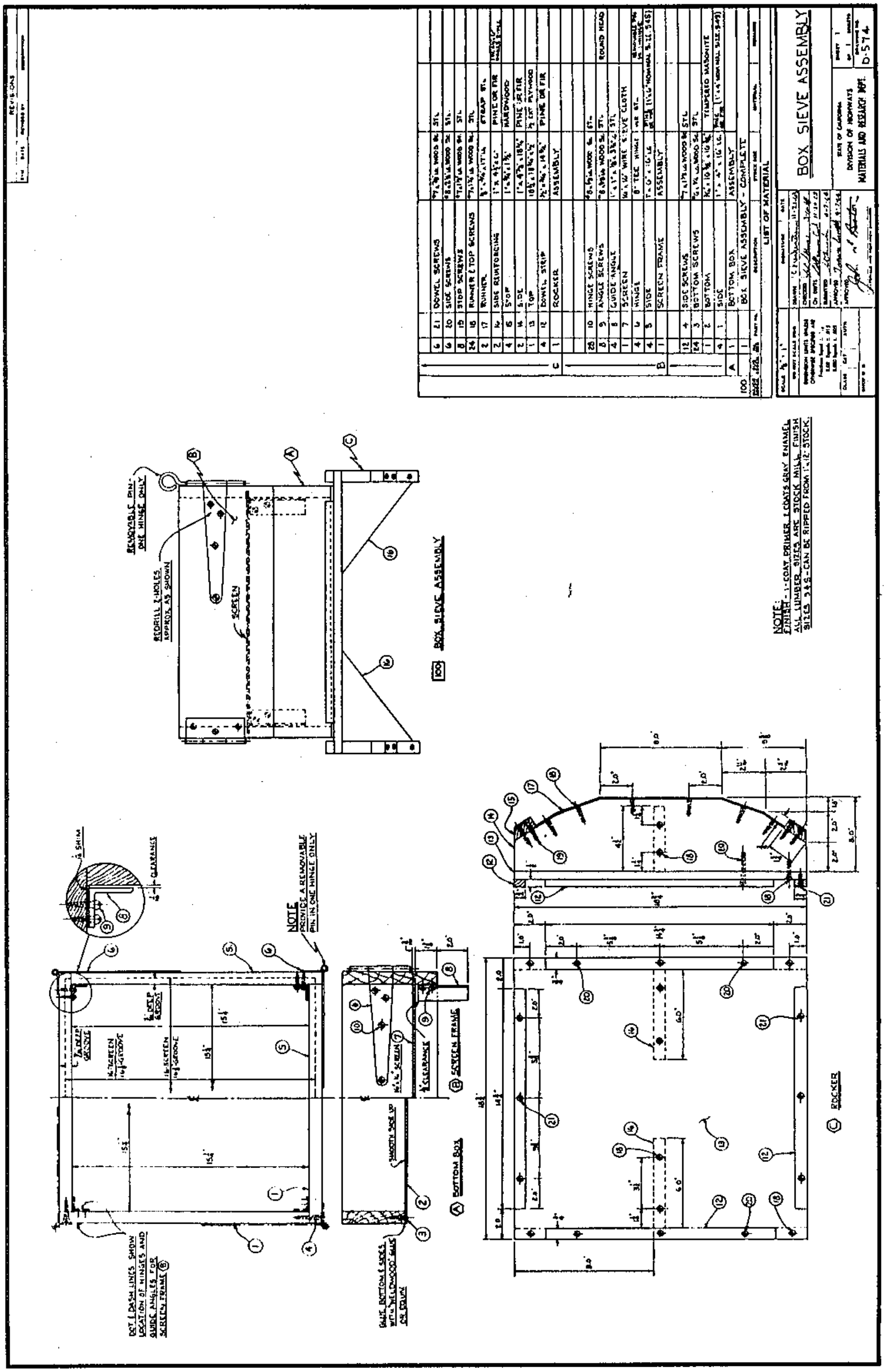


Figure I
Box Sieve Assembly

APPENDIX C

Detrition Value vs. Sodium Sulfate Soundness Loss

Various California Sources

Source Number	Name of Source	1-1/2"x3/4"* Wet DV	1-1/2"x3/4"* Na_2SO_4	1" x No. 4** Wet DV	1" x No. 4** Na_2SO_4
1	Mercer Fraser, Essex	7.6	8.0	2.7	8.0
		4.6	7.0		
2	Shirley Gundlack, Eel River	6.6	4.0	4.9	7.0
3	Eureka Sand & Gravel	---	---	3.9	9.5
4	Cotton Creek, Hornbrook	5.3	3.0	6.0	6.5
5	Teichert, Truckee	7.5	3.5	6.6	10.0
6	Rhodes & Jamieson, Pleasanton	7.7	1.0	5.0	1.5
7	Granite Rock, Aromas	6.4	2.0	5.0	2.0
8	Cal Rock, Oildale	5.4	3.5	5.0	4.0
9	Star Rock, Irwindale (Owl Rock, Santa Ana)	7.8	3.5	5.4	5.0
10	Con Rock, Sun Valley	8.6	3.0	6.5	3.0
11	Con Rock, Saticoy	6.4	5.0	7.3	10.0
12	Gillibrand, Tapo Canyon	7.0	6.0	6.4	7.5
13	Con Rock, San Juan Capistrano	4.5	3.0	4.0	3.5
14	Flintkote, Snelling	3.2	1.0	1.8	1.0
15	Con Rock, Mission Vly	2.6	1.0	3.0	2.5
16	Fenton, Otay	3.4	2.5	4.1	3.5

* Average of 2 tests
** Also designated as 3/4" x No. 4